Seasonal Variation of Pelagic Fish Catch Around Java

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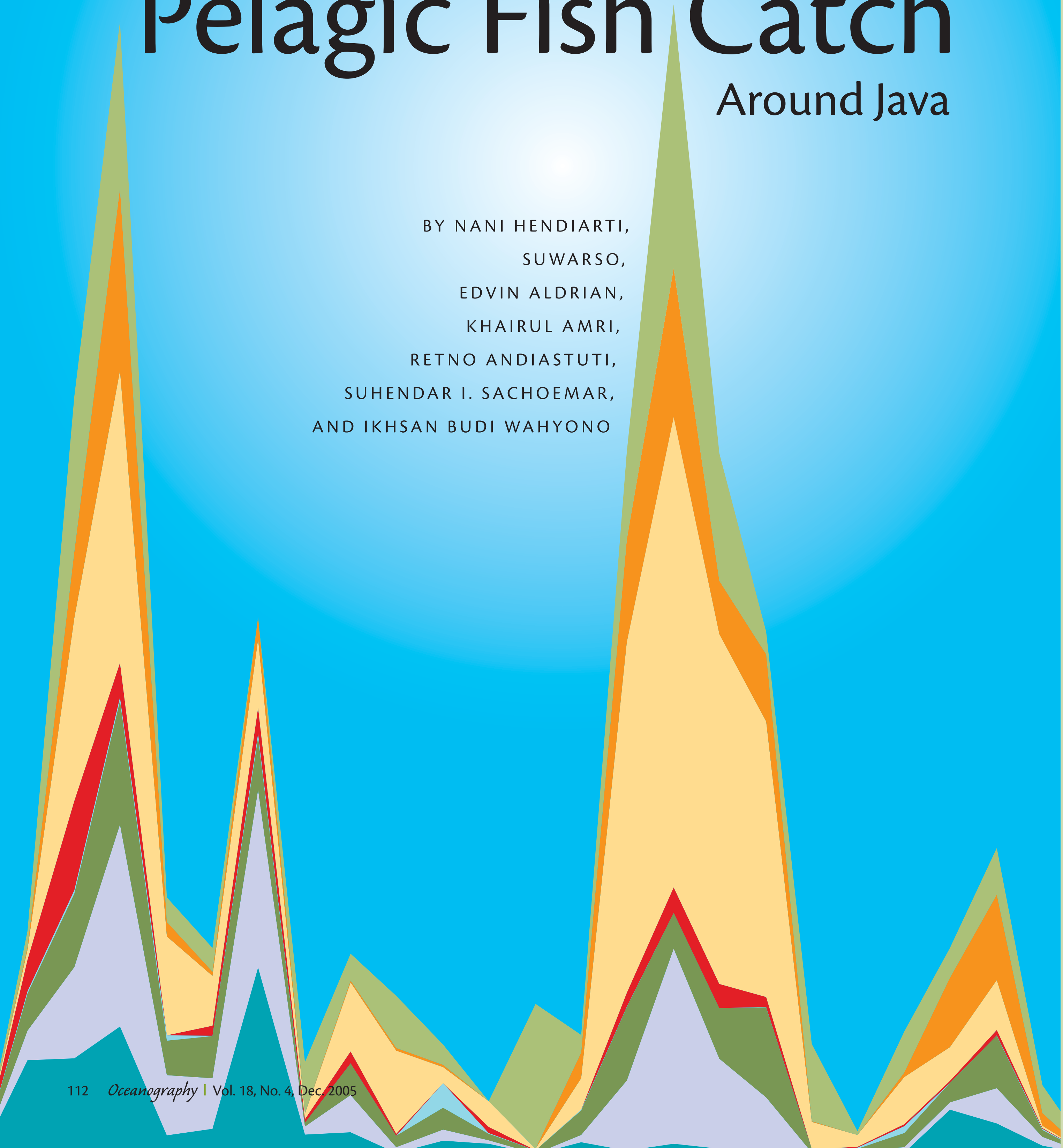

WE PRESENT DATA on the seasonal variability of small pelagic fish catches and their relation to the coastal processes responsible for them around the island of Java. This study uses long fish-catch records (up to twenty years) collected at various points around Java that were selected from the best-quality harbor records. Seven years of ocean color satellite data were also used in this study. The study selected four regions that represent the four edges of Java. Data analysis shows that the annual fish-catch pattern is determined by monsoonal activity. The monsoon greatly influences the appearance of warm and rich surface currents in the Java Sea, surface water transport and upwelling in the Sunda Strait, upwelling in the Indian Ocean, and indirect upwelling in the Bali Strait (for details on the regional oceanography, see Gordon [this issue]). These coastal processes, which differ for each region, influence fish catch and fish distribution. The natural fish stock of the entire Indonesian seas (including the Exclusive Economic Zone [EEZ]) is estimated to be 6.4 million ton/year, of which 63.5 percent are caught annually (Agency of Marine and Fisheries Research [AMFR], 2001). That fish stock consists of 5.14 million ton/year in Indonesian waters and 1.26 million ton/year in the Indonesian EEZ. Pelagic fish play an important role in the economics of fisherman in Indonesia; approximately 75 percent of the total fish stock, or 4.8 million ton/year, is pelagic fish. In particular, we investigated the waters around Java because most people live near the coast and an abundance of pelagic fish is caught under a variety of coastal oceanographic conditions.

Considering the intense fishery activities adjacent to the heavily populated island of Java, the Java Sea is presently overexploited for pelagic species (Agency for Marine and Fisheries Research [AMFR], 2001). The exploitation rate of pelagic fish in Indian Ocean of South Java is still 50 percent or less (exploitation rate is defined as catch divided by the natural fish stock at a fishing zone during the time period) (Luong, 1997; AMFR, 2001). Thus, a study such as this, which looks at the influence of coastal processes on pelagic fisheries, will be important for fish stock management on seasonal and annual bases. Study of coastal processes in the Indonesian seas, particularly around Java, can help the fisheries community understand how coastal processes correlate with fish behavior, and their abundance and seasonal distribution.

DATA AND METHODS

We investigated the seasonal variability of coastal processes in relation to pelagic fish distribution around Java using Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) data of derived chlorophyll concentrations (1997–2004) taken from the *Aqua* satellite, pelagic fish catch data collected from several harbors along the Java coast (1976–2004), and meteorological data as given by wind patterns at 850 millibars (mb).

Using SeaWiFS and MODIS data and Sea DAS computer software, all provided by the Goddard Space Flight Center of the National Aeronautics and Space Administration (NASA), we processed global area coverage data with 4-km spatial resolution as well as selected Local Area Coverage (LAC) data with 1-km resolution. We produced chlorophyll images using Ocean Chlorophyll 4-band (OC4) algorithms (O'Reilly et al., 2000). The chlorophyll determination coefficients derived from LAC data for Indonesian waters are less than 0.43 for turbid waters and greater than 0.65 for ocean waters (Hendiarti, 2003).

In addition to *Aqua* data, we used pelagic fish catch data from 1993–2003, 1992–2002, and 1985–1995, provided by the Ministry of Fisheries Affairs, were collected from documented fish landings (the quantities of fish caught and brought back to land by fisherman) in Labuan (for catches in the Sunda Strait), Banyuwangi (for catches in the Bali Strait), Pekalongan and Rembang (for catches in the Java Sea), and Cilacap (for catches in the Indian Ocean) (Figure 1). Monthly fish-catch data dominated by pelagic fish were taken from daily catches of fisherman in the fishing ground near the harbor.

RESULTS AND DISCUSSION

We used chlorophyll *a* data to observe the seasonal variation of phytoplankton blooms around Java. Different coastal processes influence the growth and distribution of phytoplankton (Figure 2). Every year, higher concentrations of chlorophyll *a* (> 0.3 mg/m^3) were observed in the Indian Ocean near Cilacap harbor in the third quarter (July–September) and lower concentrations in the first quarter (January–March) (Figure 2b). In 1998, a year after a significant El Niño, the in-

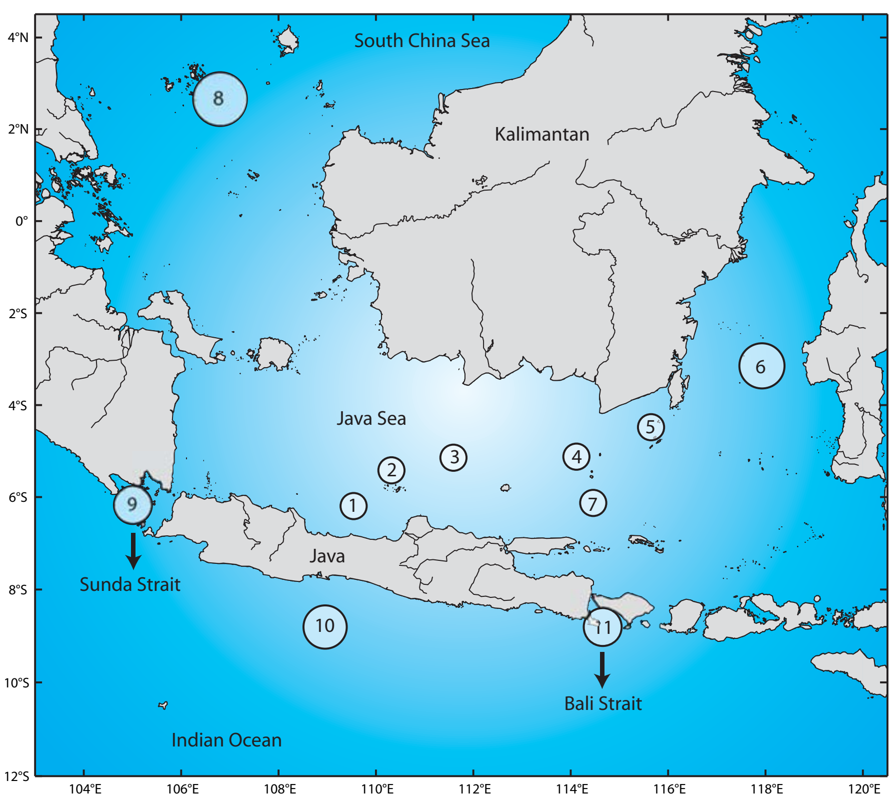

Figure 1. Map of investigation areas, including the main fishing grounds around Java.

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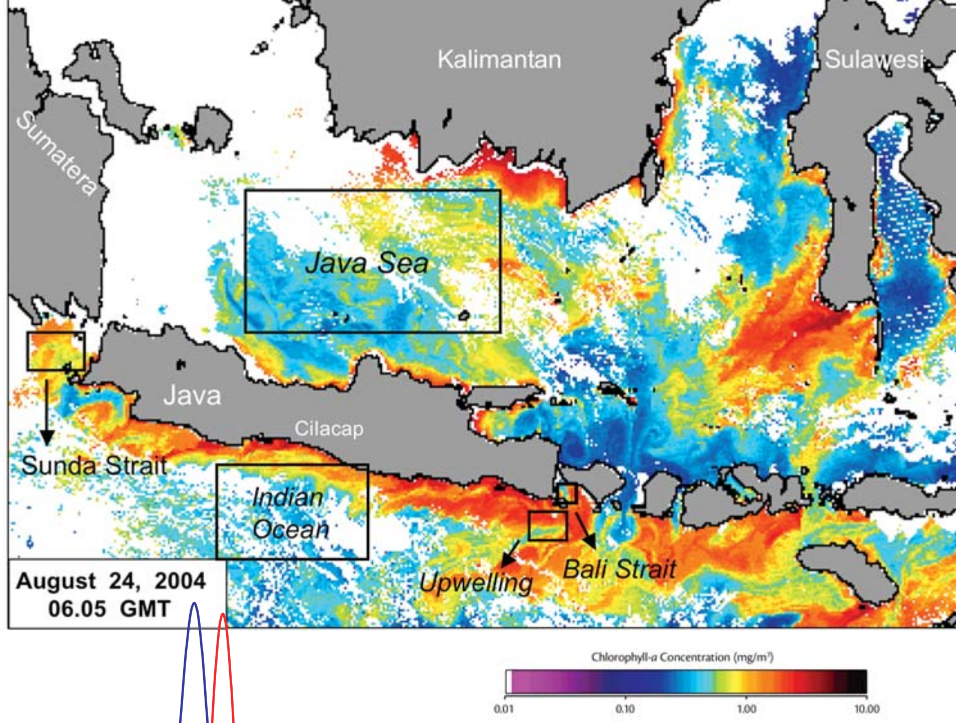

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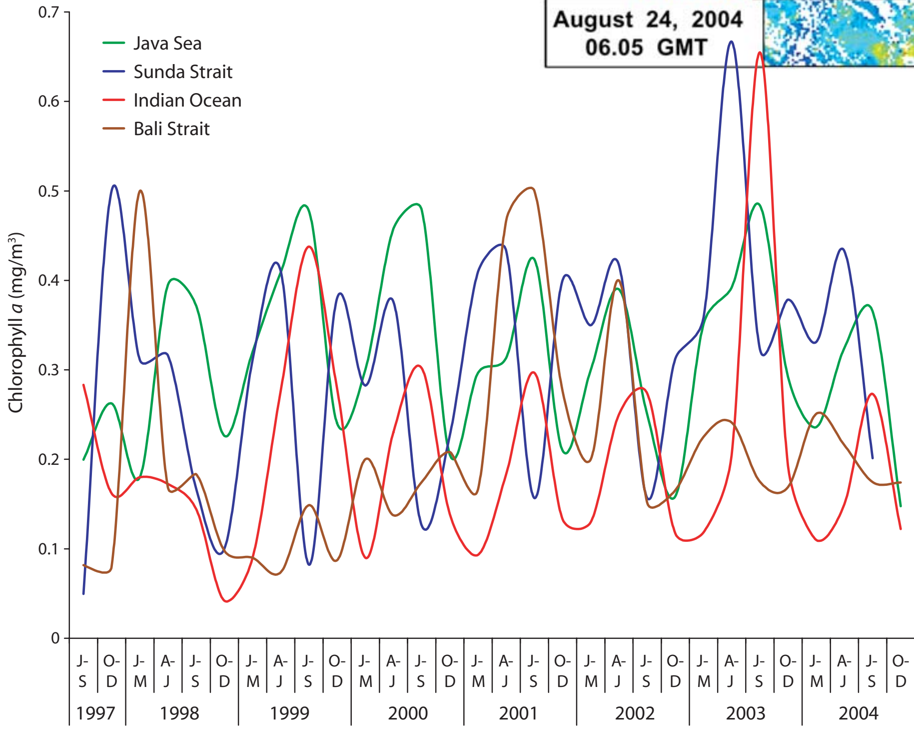
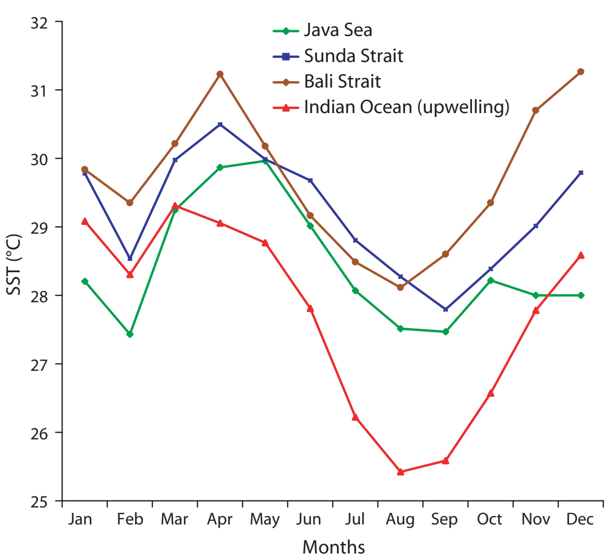


Figure 2. (a) (opposite page) Chlorophyll *a* image derived from MODIS data from August 24, 2004. (b) Average concentrations of chlorophyll in the waters around the Java from 1997 to 2004. (c) Annual changes of sea surface temperature (SST) and (d) chlorophyll concentrations of the study area (for the years 1997–2004). Note the cooling effect and an increase of phytoplankton growth in the coastal area of the Indian Ocean near Java because of upwelling during the southeast monsoon (June to October). A slight increase in SST in the Java Sea and Sunda Strait may have been caused by strong transport of freshwater and discharges during the transition phase (March to May).

c



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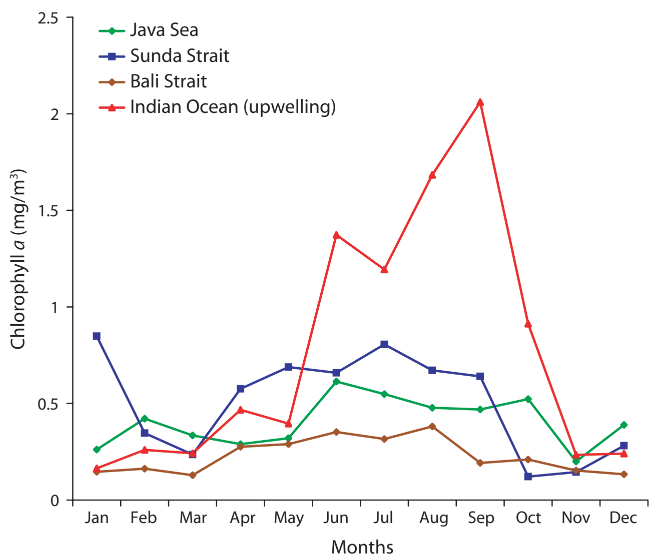

tensity and extent of phytoplankton distribution in that region from July to September were found to be less than that in other typical years (Figure 2b).

During the southeast monsoon (June to October), surface-water cooling and an increase in chlorophyll *a* concentrations in the Indian Ocean, particularly along the southern coast of Java, are in response to Ekman-induced upwelling; a slight decrease in sea-surface temperature (SST) in the Bali Strait is also a result of indirect upwelling (Figure 2c-d). Furthermore, the westward surface circulation transports nutrient-rich water from the eastern Indonesian seas into the Java Sea. These nutrient-rich waters are responsible for the slight increase in chlorophyll *a* concentrations in the Java Sea and the Sunda Strait from June to September (Figure 2c-d).

Influence of Ocean Circulation on the Distribution of Pelagic Fish Catch

In this section we present further investigations focusing on the annual trend and seasonal variation of pelagic fish caught in the Java Sea and the Sunda Strait in relation to phytoplankton distribution, oceanographic phenomena, and monsoons.

The Java Sea

Surface waters of the Java Sea seasonally travel according to monsoonal winds. Surface currents may lead to a migration of small pelagic fish, which are mostly caught by purse seine (a type of fishing net used to surround and catch large quantifies of surface-schooling fish). Hierarchically, small pelagic fish in the Java Sea can be divided into two main categories: pelagic fish caught by large purse seine in the offshore area and pelagic fish caught by mini purse seine in the nearshore area. Scattered shoaling stocks of small pelagic species are found also in the eastern part of the sea to the Makassar Strait and around the southwestern part of the South China Sea.

Approximately thirty pelagic species are caught around the Java Sea; eleven of those species account for 90 percent of the landing (Nurhakim et al., 1995). The six major species are Carangids (scads, *D. russelli* and *D. macrosoma*; trevallies, *S. crumenophthalmus*), Clupeids (sardinella, *S. gibbosa*, *A. sirm*), and Scrombids (mackerel, *R. kanagurta*,). Other species from the inshore area are often caught unintentionally, including *Selaroides leptolepis*, *Sardinella brachysoma*, *Rastrelliger brachysoma,* and *Stolephorus* spp. Potier and Sadhotomo (1995) divided these small pelagic fishes into three groups that correspond to three different types of populations among the pelagic catch: (a) oceanic population (*D. macrosoma*, *A. sirm*, *R. kanagurta*), which are caught when the oceanic waters from Banda Sea enter the Java Sea during the southeast monsoon between August and November; (b) neritic population (*D. russelli*), which are caught throughout the year by seines; and (c) coastal population (*S. crumenophthalmus, S. gibbosa*), which are caught throughout the year in lower quantities.

The annual catch of the small pelagic fish found in the Java Sea shows great variation (Figure 3). Offshore Java, the pelagic fish caught by purse seines reached about 120,000 tons in 1985 and 181,000 tons in 1994 (Figure 3a) (Potier and Sadhotomo, 1995). They observed that the increase in fish catch after 1986/1987 was the result of investments in new ships greater than 100 GT. Scads from the Java Sea were the principal contributor (approximately 50 percent) to the high total landing in 1994 from three regions surveyed (Figure 3b). Data indicate that there are two peak seasons of fish catch in the Java Sea every year with minimum catch observed from March to April and maximum catch from September to November (Figure 3c). During the peak season (September–November), most of the catch is made in the Java Sea, while from January–April most of the catch is made in the Makassar Strait (Figure 3c) (Potier and Sadhotomo, 1995). From May to June, when low-salinity waters extend eastward and reach their maximum extension, the bulk of the catch is made in the South China Sea (Figure 3c). Potier and Boely (1990) noted that this seasonal pattern is related to oceanographic variation in the area, corresponding to the monsoons.

Every year, maximum pelagic fish catch in the Java Sea occurs from September to November (Figure 4a). Two species of scads (layang, *Decapterus russelli*, and deles, *D. macrosoma*) account for at least 50 percent of the total catch and are the bulk of the catch in each of the fishing grounds (Figure 4b). There are production peaks of *Decapterus* spp. in 1984, 1989, and 1997; however, in general, *D. russelli* catch decreases when the *D. macrosoma* catch increases. The same annual trend occurs for another species of scads (*R. kanagurta*). The abundance of these two species fluctuates greatly (Figure 4b). The production peak for this species is in 1984 (Figure 4b). The landing of siro (*Amblygaster sirm*) represents up to 20 percent of the total seine catch (Figure 4b); the bulk of the catch is from the eastern part of the Java Sea.

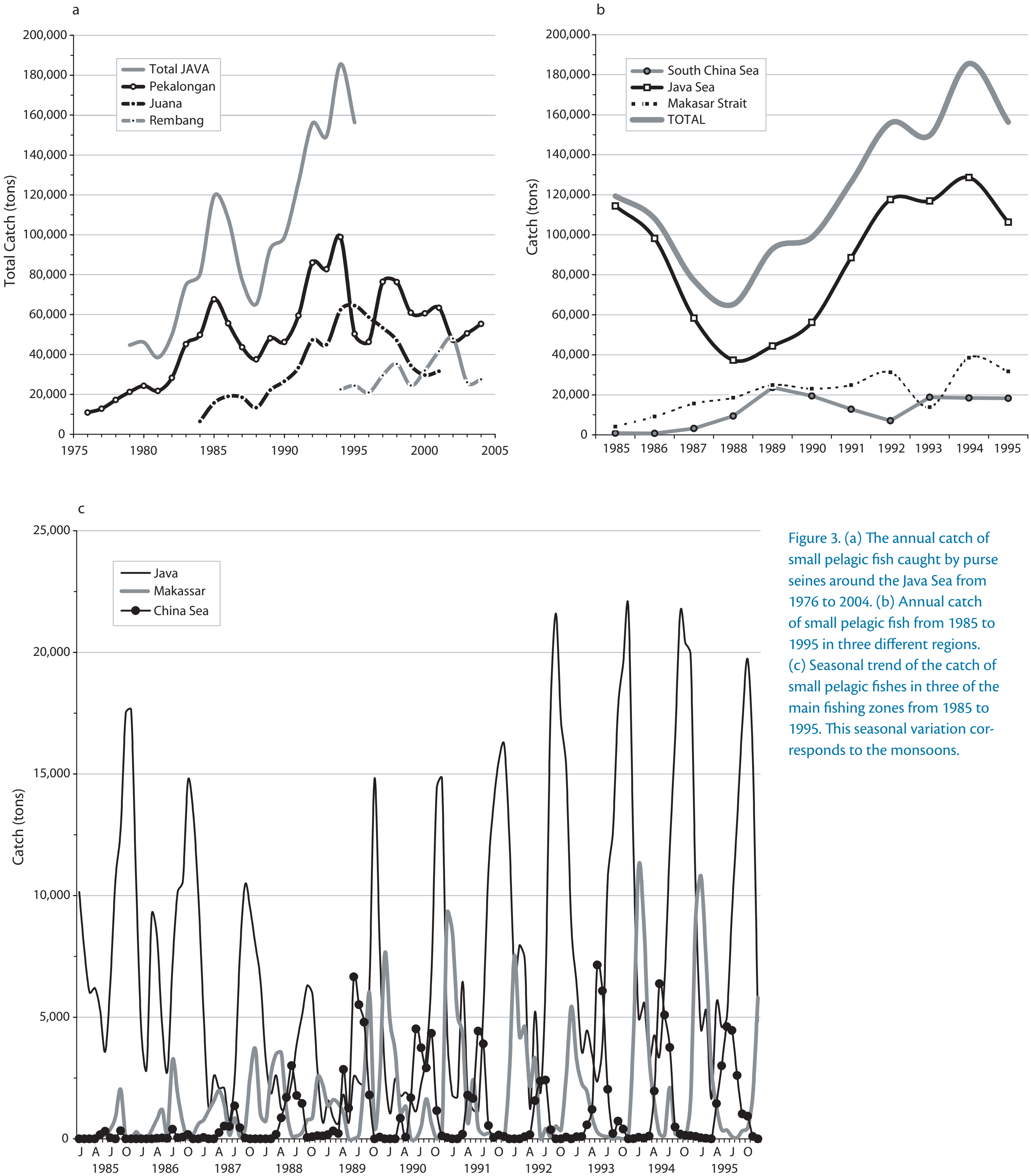

Figure 3. (a) The annual catch of small pelagic fish caught by purse seines around the Java Sea from 1976 to 2004. (b) Annual catch of small pelagic fish from 1985 to 1995 in three different regions. (c) Seasonal trend of the catch of small pelagic fishes in three of the main fishing zones from 1985 to 1995. This seasonal variation corresponds to the monsoons.

Bentong, or bigeye scads (*Selar crumenophthalmus*), were caught in a small quantity in the Java Sea as compared to the other species of pelagic fish (Figure 4b). The remainder of the catch (6–8 percent) consists of japuh (*Dusumeria acuta*), bawal hitam (*Formio niger*), and small coastal tunas (*Auxis* spp.).

Figure 4c–d plots the annual changes in species composition that show up in mini purse seine in the inshore area of the northern coast of Java. Along the central north coast (Pekalongan), a species of sardine (*Sardinella* spp.) contributes about 35 percent of the catch (Figure 4c). In addition, a neritic species (species that swim in waters less than 200 m deep) of mackerel (*R. brachysoma*) is

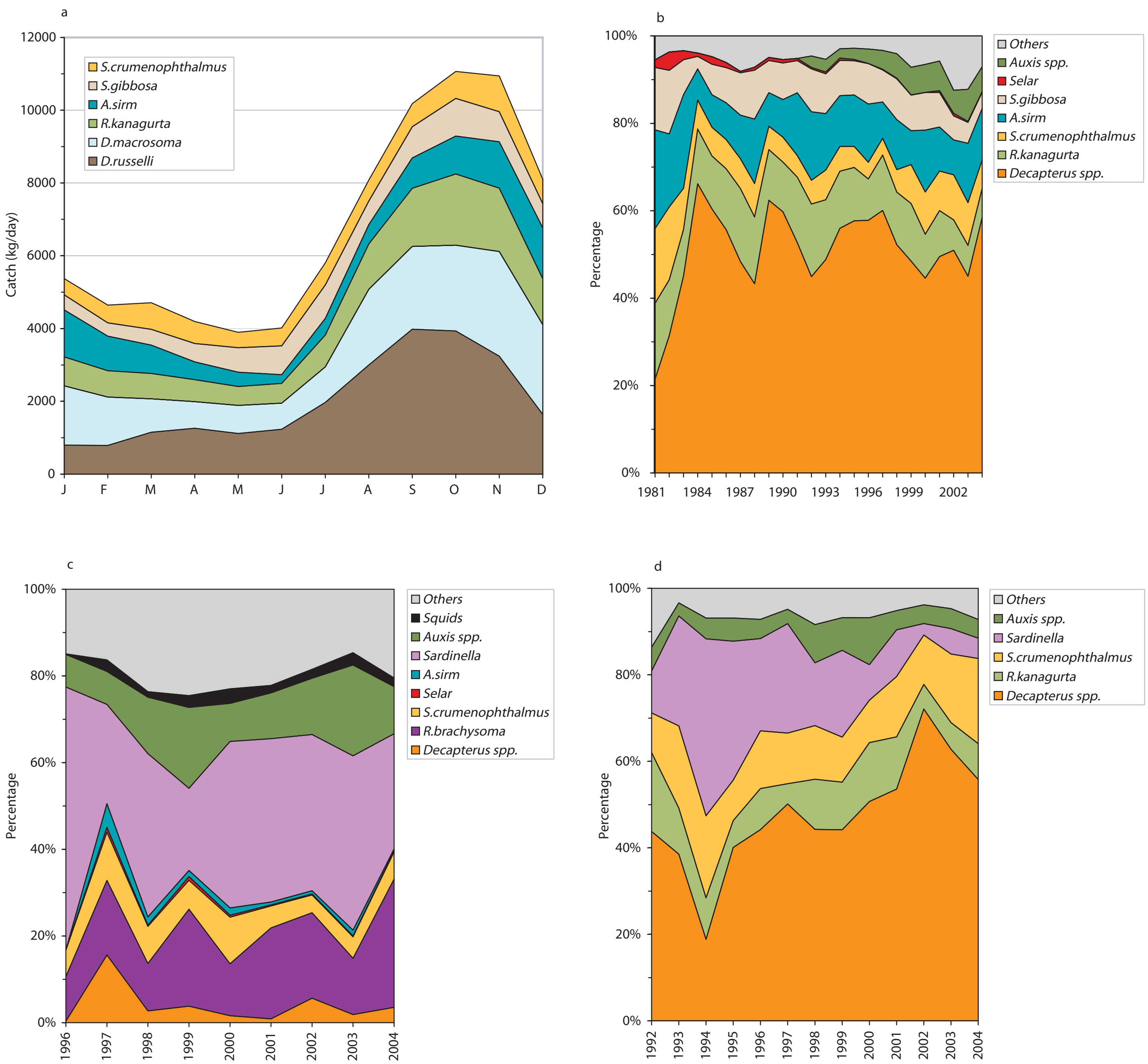

Figure 4. (a, b) Annual changes and seasonal variations of small pelagic fishes in the Java Sea. (c) Annual changes in species composition of the inshore fishery in Central Java and (d) East Java.

also dominant. This fish is an important commodity in the northwestern coast of Java (Suwarso and Hariarti, 2002) and in the south coast of Borneo (Sudjastani, 1976). During the period 1992–2004, along northern coast of east Java (Rembang), an oceanic population of scads (*Decapterus* spp.) contributes about 45 percent of the catch (Figure 4d).

Figure 5 plots the seasonal fluctuation of each species from 1981–2005. The distribution of *D. macrosoma* (an oceanic species of scads) is more concentrated in the eastern part of the Java Sea and the Makassar Strait from September to February (Figure 5a). *A. sirm* (sardines) and *R. kanagurta* (mackerel) are oceanic species that more concentrated in the central part of the Java Sea from March to June (Figure 5b). On the other hand, *S. crumenophthalmus* (a coastal species of bigeye scad) has a similar pattern to *D. russelli* (Figure 5f–g). Sadhotomo and Potier (1995) observed a size evolution of small pelagic fishes around Java; fish got larger as you went east. This trend is clearly seen for the oceanic species and might be correlated to spawning (Atmadja et al., 1995; Widodo, 1991). However, juveniles and young fish had been found inshore along the north coast of Java and Karimunjava Island from April to August (Sadhotomo and Potier, 1995). Hendiarti (2003) suggested that the occurrence of the juveniles was related to nutrient discharge, particularly from fish farms, aquaculture, and big rivers, where high concentrations of chlorophyll *a* were observed during the transition phase from the rainy to the dry season (March and April). Scads (*Decapterus* spp.) in East Java dominated the peak catch season (September–November). However, in Central Java, the sardine (*Sardinella* spp.) dominated the major peak season (March–April) and a minor peak season (October–November). This seasonal shift is also discussed in Gordon et al. (2003).

The Sunda Strait

Water flows from the Java Sea to the Indian Ocean through the Sunda Strait. The variability in water characteristics in the Sunda Strait (observed in satellite data) may influence the distribution of pelagic fish in that region (Hendiarti, 2003). During the southeast monsoon, surface waters are warm (> 29.5°C), have high chlorophyll concentrations (> 0.5 mg/m^3), and low salinity. During this period, small pelagic fish, which like the warm surface waters, are present in the Sunda Strait in higher numbers than larger oceanic species.

Pelagic fish catch data used in this study were collected from Labuan harbor from 1993 to 2003. Total fish catch per month was calculated from daily catches of fisherman, who caught mostly small pelagic species in fishing grounds near the harbor. Pelagic species were found in that region from May to August (southeast monsoon). Peak fish catch occurred annually during the southeast monsoon in June (Figure 6a). Beginning in September–October (the transition season), fish catch decreased. This decrease continued until the northwest monsoon began, and reached its lowest point in December–January (Figure 6a). The catch began to increase again in March–April (transition season).

There were differences in monthly fish catch of small (shelf originated) and big (ocean originated) pelagics during 1993, 1995, 1996, and 1997 (Figure 6b). During those years, the increase in small pelagic fish catch always occurred during the southeast monsoon, but was not followed by similar trend in large pelagic fish. If we compare the dominant catch of small pelagic fishes (selar bentong [*Selar crumenopthalmus*, or bigeye scad], banyar [*Rastreliger kanagurta*, or striped mackerel], tenggiri [*Scromberomenus comersonii*, or barred Spanish mackerel]), and large pelagic fishes (tongkol [*Euthynnus* spp., or coastal tuna/frigate tuna]), we find that both small and larger pelagic fishes are present and have similar seasonal patterns in the Sunda Strait. Frigate tuna, striped mackerel, bigeye scad, kembung, tembang, and scad catches begin in March (transition season); the catch increases as it enters the southeast monsoon season, the peak of catch season (Figure 6b). The catch then decreases when the next transition season comes, and reaches its minimum during the northwest monsoon. This observed annual fluctuation agrees with Pakpahan's (1999) conclusions. He suggested that the small pelagic fish catch in the Sunda Strait will start in the same month every year (April) and will end in the same month (November). However, the start and end of the fish catch could come earlier or later and follow with forward or backward production outcomes.

Influence of Upwelling Events on the Distribution of Pelagic Fish

Indian Ocean

In upwelling regions, the intensity of nutrient inflow from deeper layers increases phytoplankton abundance. These upwelling regions are suitable for fish because they provide good feeding conditions for larvae, juveniles, and adult pelagic fish. Larvae and juveniles feed on plankton. The fish catch in Cilacap

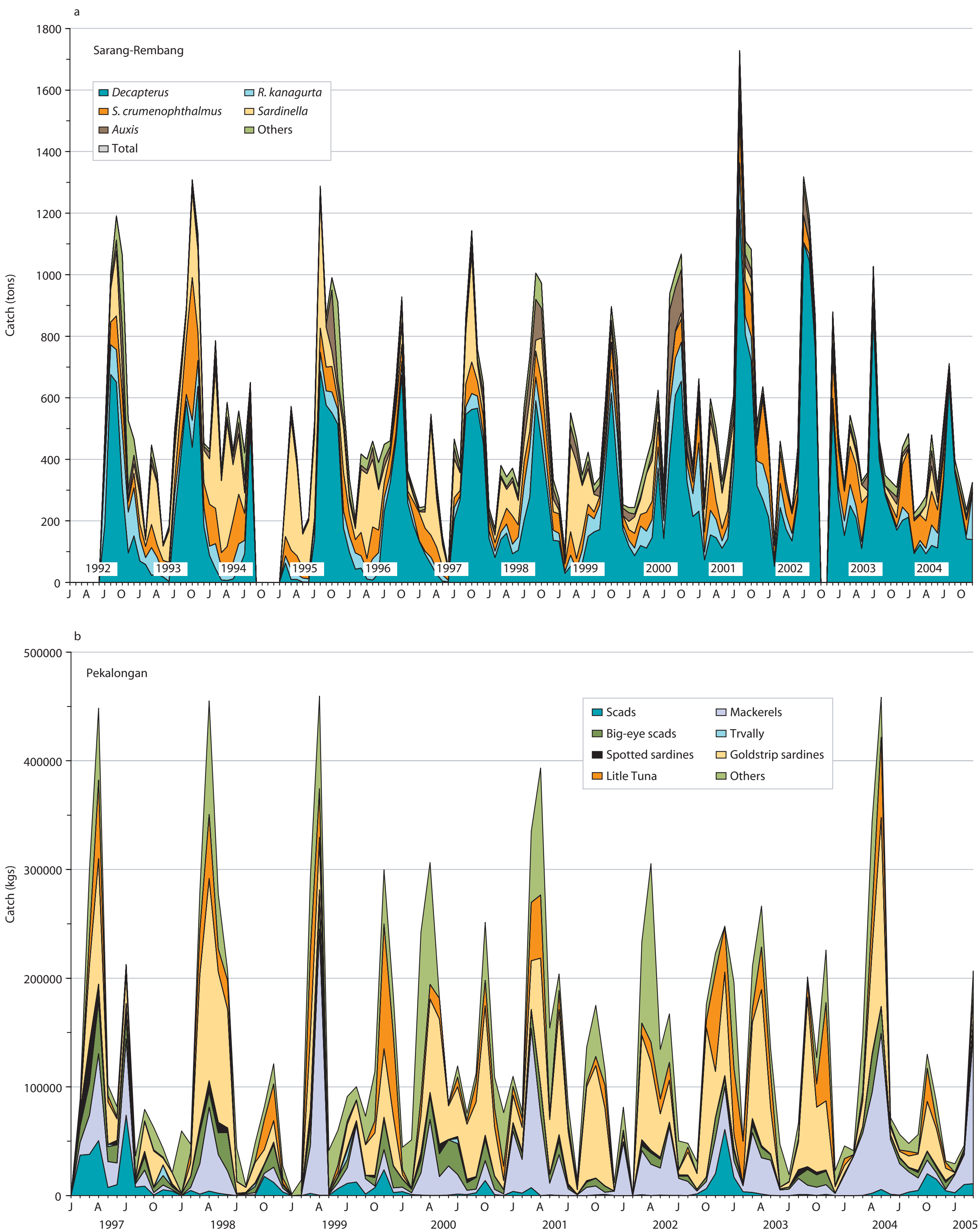

Figure 5. Fluctuation of small pelagic species in the inshore north coast of (a) East Java and (b) Central Java from 1992–2005.

harbor from 1998 to 2004 was dominated by the large pelagic fish skipjack (*Katsuwonus pelamis*), tuna (*Thunnus albacores*), layar (*Istiophorus* spp.), tenggiri (*Scomberomorus* spp.), cucut (*Isurus glaucus*), tongkol (*Euthynnus* spp.), and blue marlin (*Thunnus* spp.). During the southeast monsoon, high amounts of chlorophyll *a* in the surface waters are correlated with high catches of cakalang. However, for the tuna fish catch, the fertility of the South Java water in August is not followed by an increase in tuna catch. From Banyuwangi fish harbor, we observed a high abundance of small pelagic schooling fish like *sardinella* in upwelling areas off the southern coast of East Java, which is characterized by cold water and high surface chlorophyll. Tuna (*Thunnus* spp.) is a pelagic predatory fish that consumes small pelagic fish. Primary production does not aggregate tuna, but development of secondary production provides an attractive habitat for tuna species. Tuna aggregations are often found close to the frontier zones, which are important places for aggregating plankton and micronekton (e.g., Lehodey et al., 1998). Therefore, high abundance of tuna may also occur close to highly productive upwelling zones.

The Bali Strait

Sadinella Lemuru is the dominant species (more than 90 percent of total catch) in the Bali Strait's pelagic fishery, and is mainly exploited by the purse seiners. Annual fluctuation is great in this fishery, with three large peaks in production from 1974–2000: 1983, 1991, and 1998, reaching 48,000 tons, 61,670 tons, and 77,600 tons, respectively (Merta, 1992a,b). The lowest production was in 1986, 1996, and 1999. Seasonally, during 1992–2002, the catch of lemuru fluctuates greatly. It has two peak seasons (Figure 7). The major peak is from September to November, while a minor peak sometimes occurs from March to April. The production in 1993, 1994, 1997, and 2001 is known as the "normal" pattern, whereas the production in 1995, 1996, 1998, 1999, and 2000 is known as the "uncommon" pattern (Wudianto, 2001). In 1995 and 1998, higher production also occurred from January to July. Wudianto (2001) suggested that those two years were the uncommon periods of catch fluctuation. Spawning season occurs in June and July every year (Merta, 1992a,b), which coincides with the presence of upwelling during southeast monsoon season (Burhanuddin and Praseno, 1982; Saliyo, 1973). The bulk of "semenit" (size category of lemuru at 1–2 months old) is present during August

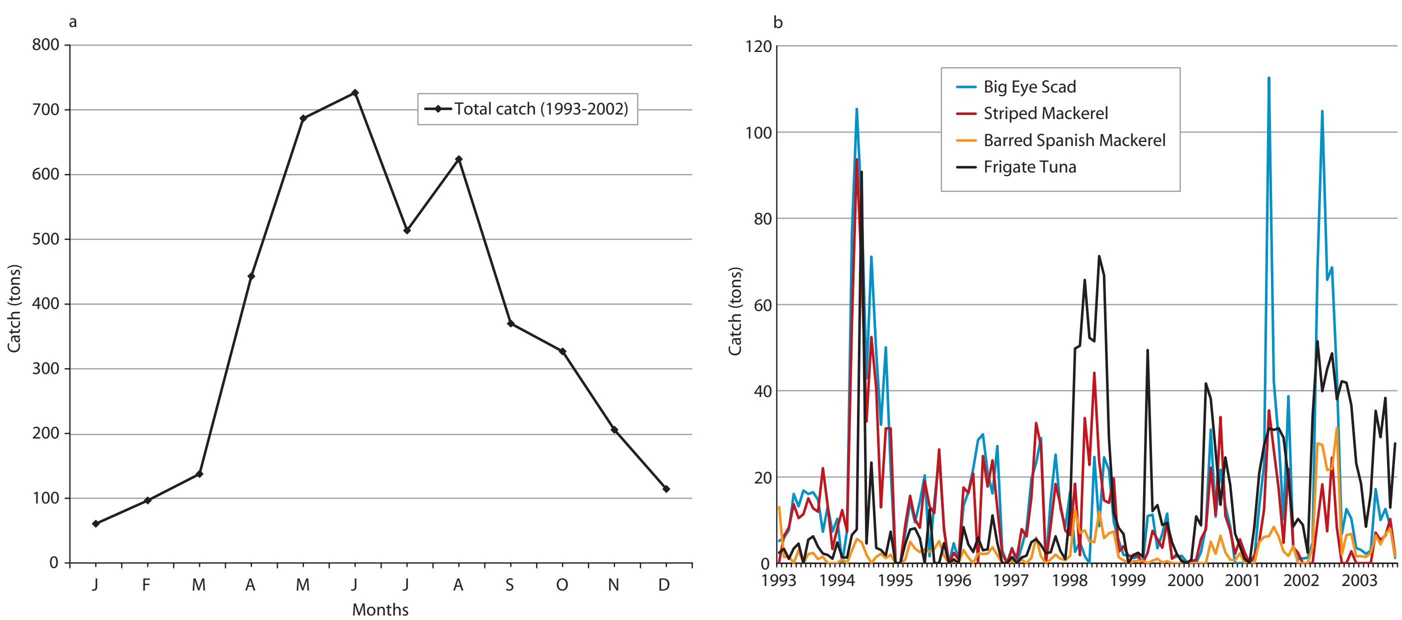

Figure 6. (a) Average annual variability in total pelagic catch from Labuan Fishing Port, Sunda Strait from 1993–2002. (b) Annual catch fluctuation of pelagic fishes in the Sunda Strait from 1993–2003. Pelagic fish-catch data were collected from daily catches of fisherman. Big pelagic fish are frigate tuna; small pelagic fish are bigeye scad, striped mackerel, and barred Spanish mackerel.

and September, while adult fish (mature) are usually present in May (Merta, 1992a,b). Seasonal fluctuation of the catch is highly correlated with changes in oceanographic condition.

CONCLUSIONS

We have described, examined, and analyzed variability of fish catches, and their correlation to seasonal coastal processes, from four different harbors around Java: the Java Sea (north), the Sunda Strait (west), the Bali Strait (east), and the Indian Ocean (south). The findings of this study are summarized in Table 1. Development of phytoplankton in specific regions is related to coastal and ocean processes forced by wind. Remote sensing of ocean color provides the general characteristics of various ocean phenomena around Java, including surface water transport, coastal discharge in the Java Sea and Sunda Strait, and coastal upwelling along the southern coast of Java. Upwelling is characterized by high chlorophyll concentrations and low sea surface temperature, while surface transport of the Java Sea water into the Sunda Strait is distinguished by higher chlorophyll concentrations and higher sea surface temperatures. We identified the characteristics of pelagic fishes around Java—their dominant species, the duration in specific waters, and when they appeared.

The monsoonal system in the Indonesian archipelago plays a great role in determining the variability of fish catch around Java. The "pelagic fish season" develops during the southeast monsoon. Variability in the annual fish catch patterns from the four regions show similar maximum and minimum peaks during the southeast and northwest monsoon, respectively. However, it turns out that for each region, the monsoon system affects coastal processes differently, which influences the variability of the fish catch and fish distribution.

Interannual variability of the fish catch is determined by many factors, including oceanographic processes and human factors such as fishing skill and fish-catch equipment. Seasonal variability in sea-surface conditions is similar from year to year and interannual variability is predictable. Due to lack of data, there is no detailed study on the interannual variability of all coastal processes except sea surface temperature and chlorophyll *a* concentration. There is also no clear indication of the role of regional phenomena such as El Niño and La Niña events in influencing fish catch.

Results of this study were built from long fish-catch records around Java. They represent the best records from harbors along each of the island's four coasts. Physical oceanography results provide an explanation for variability in fish catches, which may help decision-makers, such as fish stock analyzers, determine future fish-catch policy around Java. More detailed investigations of the interannual variability of all coastal processes and why they fail to explain the interannual variability of the fish catch is needed. Future studies could also be extended to include large pelagic fish or additional species.

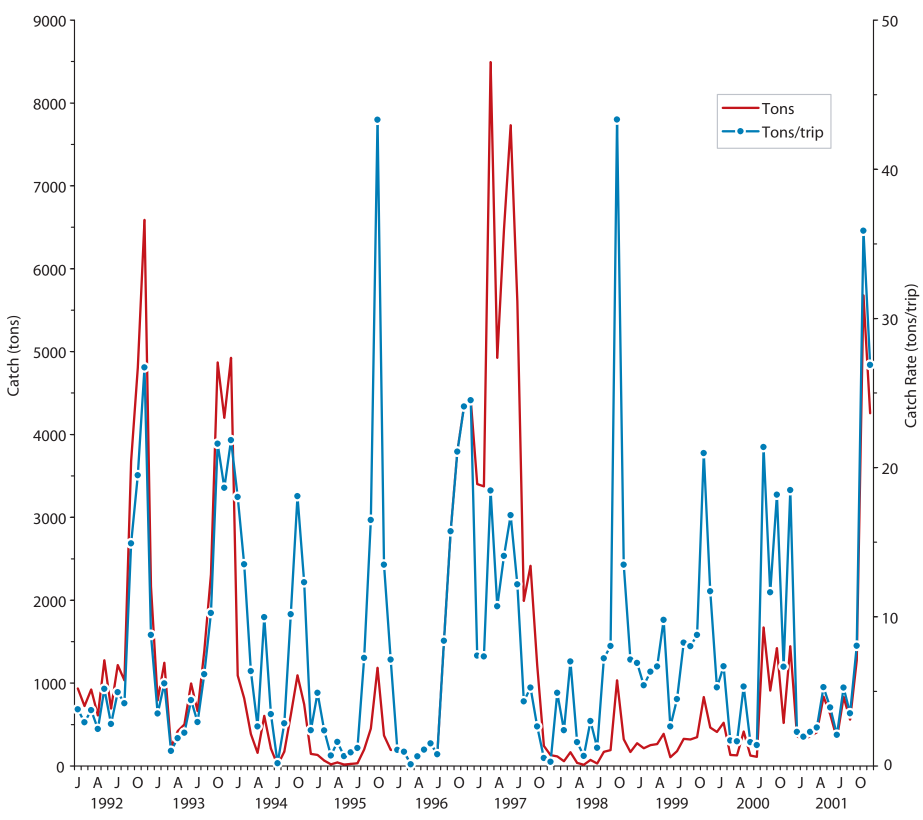

Figure 7. Fluctuation of the catch (tons) and catch rate (ton/trip) of Lemuru (*Sardinella lemuru*) in the Bali Strait landed at Muncar (East Java) from 1992–2001.

Table 1: Characteristics of pelagic species and ocean phenomena.

Regions	Dominant Pelagic Species	Characteristic (when appear)	Ocean Phenomena
Java Sea	Small Pelagic: (a) oceanic: *D. macrosoma*, *A. sirm*, *R. kanagurta*; (b) neritic: *D. russelli*; (c) coastal: *S. crumenophthalmus*, *S. gibbosa*	Max: Sep. – Nov. (southeast monsoon)	Warm and high nutrients surface water
		Min: Mar. – Apr.	-
Sunda Strait	Small Pelagic: *Sardinella* spp., *Rastrelliger* spp., *Selaroides leptolepis*, *Decapterus* spp. Big Pelagic: *Auxis thazard*, *Scomberomorus* spp.	Max: Jun. (southeast monsoon)	Surface water transport and upwelling
		Min: Dec.	-
Indian Ocean	Big Pelagic	Max: Jun. – Sep. (southeast monsoon)	Upwelling
		Min: Nov. – Jan.	-
Bali Strait	Small Pelagic: *S. lemuru*	Max: Sep. – Nov. (southeast monsoon)	Inflow of recently upwelled water
		Min: Mar. – Apr.	-

ACKNOWLEDGEMENTS

The authors wish to thank the Marine Fishery Research Institute and the Ministry of Marine and Fishery Affairs for their data support and fruitful discussions.

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